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Contents

On the nature of HESS J1503-582 revealed by the H.E.S.S. experiment: Coincidence with a FVW?

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Abstract.
The H.E.S.S. survey of the inner Galaxy in the very-high-energy (VHE; E > 100 GeV) gamma-ray domain has led to the discovery of many extended sources, some of which do not appear to be associated with any obvious counterpart at traditional wavelengths (radio, infrared and X-ray). In this contribution, preliminary H.E.S.S. results on one of these so-called "dark" sources, namely HESS J1503-582, are presented. After introducing the properties of this source candidate, results of the search for counterparts in several astronomical windows are shown. Finally, its possible association with a "Forbidden-Velocity-Wing", a characteristic 21 cm HI line structure that appears as a deviation from the canonical Galactic rotation curve, is discussed.

Keywords: Astronomical Observations: γ-ray – ISM and nebulae in Milky Way: HI regions and 21-cm lines; diffuse, translucent, and high-velocity clouds, Supernova remnants – Characteristics and properties of the Milky Way galaxy: Galactic winds and fountains
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INTRODUCTION

Almost twenty years after the detection of the first TeV γ-ray source, the Crab nebula [1], current Imaging Atmospheric Cherenkov Telescopes (IACTs) have opened a new astronomical window with $\sim$ 70 sources detected so far [2]. More than 50 of these new VHE γ-ray emitters are of Galactic origin and their detection is largely a consequence of the survey conducted by H.E.S.S., which now covers the entire inner Galaxy (see [3], these proceedings). A significant fraction of these sources do not appear to be associated with objects which are known as potential sources of VHE γ-rays, such as Supernova Remnants (SNRs) and Pulsar Wind Nebulae (PWNe). This is likely due to the difficulty of identifying extended (*i.e.* on the order of tens of arcmins) sources with no clear sub-structure. Although current IACTs have reached unprecedented sensitivities and angular resolutions, the morphology of most of these faint sources can not be characterised precisely. Moreover, instruments in other domains (radio, infrared, X-ray) usually feature angular resolutions at the arcsecond / sub-arcminute scales, often coupled with relatively small fields of view compared to H.E.S.S., which prevent one from revealing large-scale structures. Generally speaking, every catalog of potential TeV sources is known to be biased and incomplete, as exemplified by that of Galactic SNRs [4]. Therefore, some sources may show up in the VHE channel while being hardly detectable in other observational windows. In this contribution, H.E.S.S. observations and data analysis on one of these so-called "dark" sources, namely HESS J1503-582, are introduced. Its properties together with the results from the search for traditional counterparts such as SNRs, energetic pulsars and PWNe, star-forming complexes, HII regions and Wolf-Rayet (WR) stars, are then presented. Finally, its possible association with a "Forbidden-Velocity-Wing" (hereafter, FVW), a characteristic 21 cm HI line structure lying beyond the canonical Galactic rotation curve, is discussed. All results presented here are preliminary; further studies of this source candidate are in progress.

H.E.S.S. OBSERVATIONS & ANALYSIS

H.E.S.S. (High Energy Stereoscopic System) comprises four identical 12 m diameter IACTs located in Namibia. Sensitive to γ-rays above $\sim$ 100 GeV, the H.E.S.S. array commonly achieves an angular resolution of about 0.1° and an energy resolution of about 15%. The region of interest was first targeted as part of the observational programme on the VHE PWN of MSH 15-52 in 2004 [5]. The region was later observed regularly until 2007 as part of the extended H.E.S.S. Galactic Plane Survey. The data set (see Figure 1) was first investigated using the standard survey analysis (an on-source region with a radius of $\theta_{cut} = 0.22^\circ$, a ring background region with a radius of 0.8° and hard cuts, which include a minimum requirement of 200 photo-electrons per shower image for γ-ray selection) as described in [6]. An extended, 5-σ ex-

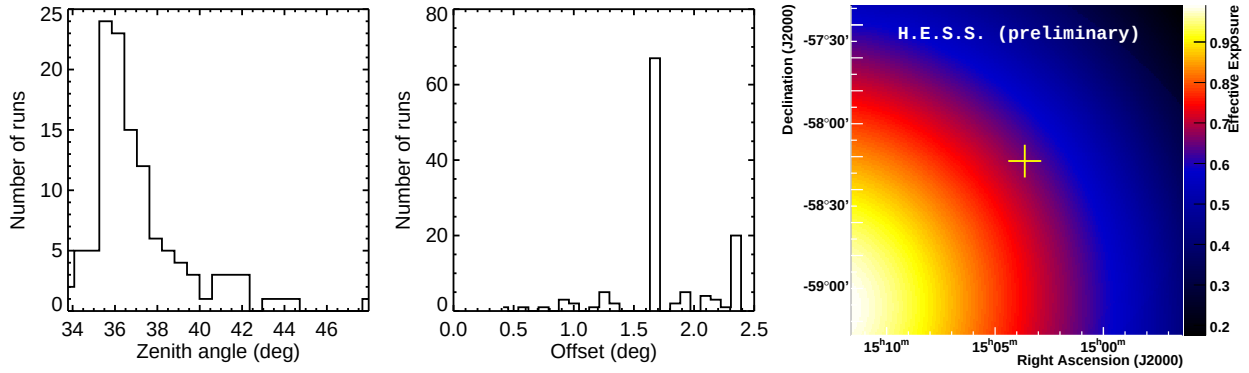

FIGURE 1. *Left:* Distributions of zenith angles and pointing offsets relative to HESS J1503-582 of selected runs. *Right:* Map of the effective exposure (normalized) showing a significant exposure gradient in the direction of MSH 15-52, which is $\sim 1.5^\circ$ away from HESS J1503-582. In order to mitigate any potential systematic effects, an additional cut was applied, such that only runs with offsets less than 2° were selected. The zenith angles of the observations range from 35° to 45°, leading to a typical energy threshold of about 800 GeV.

cess at l $\sim 319.7^\circ$ and b $\sim 0.3^\circ$ was discovered, namely HESS J1503-582.

After selecting only runs with four telescopes which pass the usual quality criteria (in order to remove data affected by unstable weather conditions or hardware issues), the data set has an acceptance-corrected live-time of about 24 h at the position of HESS J1503-582. Two independent data analyses, namely the Hillas [7] and Model 2D [8] methods, were used to generate sky maps and spectra. Both analyses give consistent results. In the following, only those obtained with the Hillas method are shown. Sky maps (Figure 2) were produced using the Ring Background method for background subtraction, while spectra (Figure 3) were generated using the Reflected Region Background method [9].

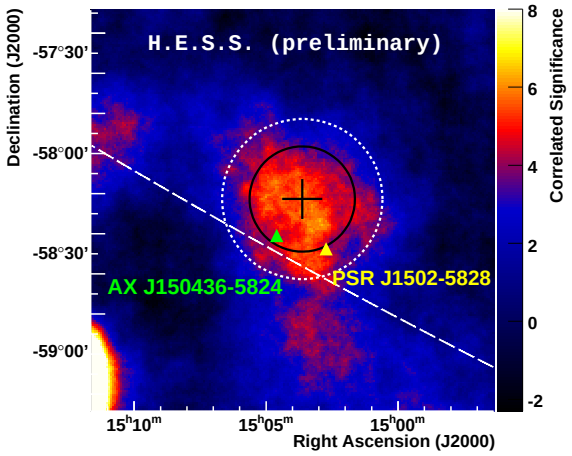

FIGURE 2. H.E.S.S. image of the correlated significance (R = 0.3°) centered on HESS J1503-582. Its peak significance reaches 6 σ (pre-trials). The black cross and circle denote the uncertainty of the source centroid ($\sim 0.1^\circ$) and its intrinsic rms size of 0.26°, respectively, after fitting with a 2D Gaussian. The outer, dotted white circle represents the region of spectral extraction. The Galactic Plane is shown as the dashed line. The two objects AX J1504.6-5824 and PSR J1502-5828 are discussed in the next section. The bright source in the lower left corner is MSH 15-52.

MULTI-WAVELENGTH DATA

Search for traditional counterparts

While searching multi-wavelength catalogues (in radio, infrared and X-ray) within 0.3° around HESS J1503-582 through the Simbad database, two interesting sources were found at first glance:

- AX J1504.6-5824 [10]: Catalogued as a Cataclysmic Variable, given the high column density N(H) = 1.29×10^{22} cm^{-2} and a hard photon index $\Gamma = 1.44$ in the 2–10 keV band. However, the lack of additional X-ray data from *XMM-Newton*, *Chandra* or *Suzaku* prevents one from drawing firm conclusions about its nature.
- PSR J1502-5828 [11]: An old pulsar ($\tau_c = 0.29$ Myr) with a very low spin-down flux of 3.3×10^{31} (d / 12 kpc)$^{-2}$ erg s^{-1} kpc^{-2}. This value correponds to roughly half of the measured integrated flux above 1 TeV of HESS J1503-582, which makes the association unlikely; other γ-ray emitting PWNe usually exhibit a flux of 10^{-3} - 10^{-2} of the spin-down power [12].

No counterpart was found in catalogues of potential TeV emitters such as Galactic SNRs [4], HII re-

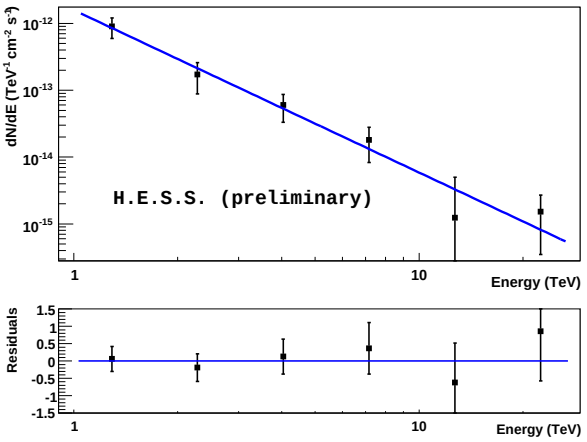

FIGURE 3. Differential energy spectrum of HESS J1503-582 between 1.3 and 22 TeV. The coordinates (J2000) of the extraction region are centered on the fit value from Figure 2: R.A. = 15^h03^m38ß and Dec. = -58°13′45″ with a radius = 0.4°. The data points are fit with a power law with photon index $\Gamma = 2.4 \pm 0.4_{stat} \pm 0.2_{syst}$ and a normalization at 1 TeV of $(1.6 \pm 0.6_{stat}) \times 10^{-12}$ cm^{-2} s^{-1} TeV^{-1}. The integrated flux above 1 TeV, of about 6×10^{-12} erg cm^{-2} s^{-1}, corresponds to roughly 6 % of that of the Crab nebula. Also shown are the residuals in the bottom panel.

gions [13], star-forming complexes [14] and WR stars [15]. The radio archival public images from Molonglo at 843 MHz, ATCA at 1.4 GHz, Parkes at 2.4 GHz, and Parkes-MIT-NRAO (PMN) at 4.85 GHz, as well as infrared images from MSX (at 8.28, 12.13 and 14.65 μm [1]) and Spitzer/GLIMPSE (at 8 μm [2]) were also inspected to search for hints of diffuse emission coincident with HESS J1503-582, but no such emission was found.

Coincidence with a FVW?

The search for traditional counterparts, as discussed above, did not reveal any likely candidates. However, Kang & Koo [16] have published a catalog of 87 extended and faint radio structures detected through the 21 cm HI line in the SGPS and Leiden/Dwingeloo Survey (LDS) data. These structures, so-called Forbidden-Velocity-Wings (FVWs), appear as wings of line emission at velocities forbidden by the canonical Galactic rotation curve in limited spatial regions over velocity extents of more than $\sim$ 20 km s^{-1} (see Figure 4, left). Among them, FVW 319.8+0.3, marked with the highest detection rank by Kang & Koo [16], is spatially coincident with HESS J1503-582, as shown in Figure 4 (middle). This FVW appears in the HI line image integrated between -123 and -98 km s^{-1}, two velocities which are not permitted by the canonical Galactic rotation curve [17] along this line of sight (Figure 4, right).

This FVW does not coincide with any known objects that could be responsible for its large velocity, *e.g.* SNRs, nearby galaxies, or high-velocity clouds. Most of the detected FVWs are located off the Galactic Plane, and their atypical latitude distribution lead [16] to discuss possible origins. For instance, previously unknown, old SNRs in the radiative phase could be the most likely candidates, as in the case of the discovery of the SNR associated with FVW 190.2+1.1 [18]. Thus, the Southern Galactic Plane Survey (SGPS) HI data [19] have been inspected to search for any shell-type diffuse emission in the velocity range of FVW 319.8+0.3, since ATCA features a better angular resolution ($\sim 2'$) than Parkes ($\sim 15'$). No shell-type structure was found, but the low ATCA sensitivity of ~ 1.6 K renders the identification of faint and extended emission difficult.

Such old, isolated SNRs (*i.e.* those with an age greater than the onset of the radiative phase $\sim 3.6 \times 10^4$ y [20]) are not expected to accelerate multi-TeV particles any longer, mainly because of the very low shock speed [21]. On the other hand, the joint activity of stellar winds and SN explosions from massive stars in nearby (< 4 kpc) and powerful ($> 10^{37}$ erg s^{-1}) OB associations could produce fast-moving neutral hydrogen gas detectable at the sensitivity level of the current HI surveys [16]. Recently, H.E.S.S. detected extended VHE γ-ray emission in the direction of the young stellar cluster Westerlund 2, hosting the massive WR binary WR 20a and located in the HII complex RCW 49 [22]. This source is currently the only clear exemple of an association between VHE γ-ray emission and a young stellar cluster / wind-blown bubble ([23] discuss the status of HESS J1848-018 in this regard). However, it would not be unlikely if, among all of the known "dark" sources, some of them actually belong to this class of VHE γ-ray emitters. Deeper investigations of infrared data and follow-up observations of HESS J1503-582 will then help constrain such scenario.

CONCLUSION

The H.E.S.S. Cherenkov telescope array has proven itself to be the most efficient in revealing new faint and extended VHE γ-ray sources. Among them, the source candidate HESS J1503-582 does not appear to have any obvious counterpart at traditional wavelengths. With an observing strategy designed to reduce the gradient in the current exposure map, more data will soon be taken in order to confirm this detection. Follow-up X-ray observations with *XMM-Newton*, *Chandra* and *Suzaku* are also

[1] see `http://irsa.ipac.caltech.edu/data/MSX/`
[2] see `http://irsa.ipac.caltech.edu/data/SPITZER/GLIMPSE/`

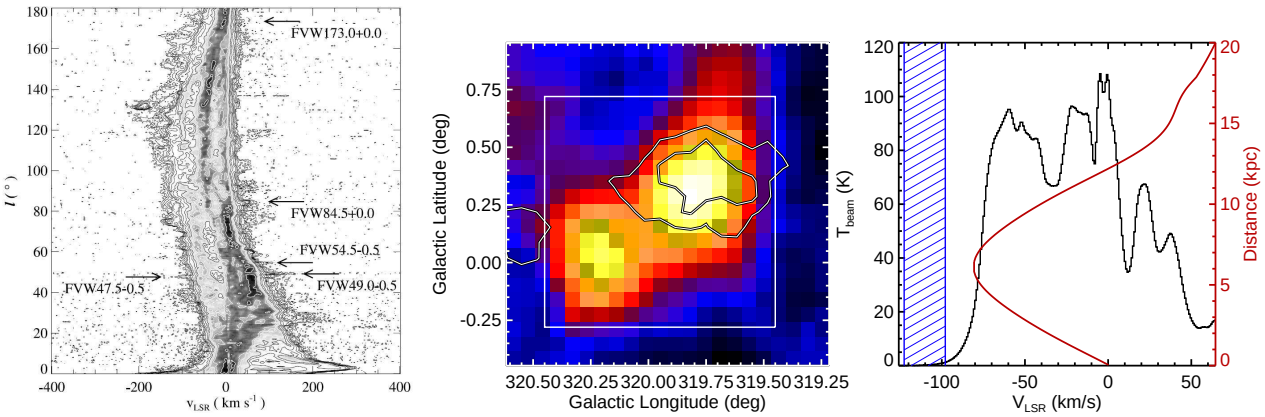

FIGURE 4. *Left:* LDS (l-v) diagram of the first and second quadrants (b = -0.5°) showing some of the FVW structures extending beyond the Galactic Plane (from [16]). *Middle:* SGPS (Parkes) velocity-integrated (between -123 and -98 km s^{-1}) image of the HI line emission centered on FVW 319.8+0.3. H.E.S.S. significance contours are shown in black at 4 and 5 σ levels. *Right:* Velocity profile of HI intensity integrated over the white square shown in the middle panel. The red curve represents the canonical Galactic rotation curve according to [17] at the position of FVW 319.8+0.3. The velocity range of the image in the middle is shown by the blue dashed region.

needed in order to constrain the nature of the ASCA hard X-ray point-like source close to HESS J1503-582. The association with a FVW, if confirmed, would represent the first source of VHE γ-rays coincident with such an HI structure. These structures could be the result of the combined activity of stellar winds and supernova explosions that are detectable only through this channel.

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